Effect of Physical Parameterizations on the Performance of a Coupled Ocean-Atmosphere GCM

Chung-Chun Ma,[1] Carlos R. Mechoso, and Akio Arakawa

Department of Atmospheric Sciences, University of California
Los Angeles, California, U.S.A.

1. Introduction

Prediction of climate variations on seasonal and interannual time scales requires consideration of the interactions between oceans and atmosphere. The simulation of climatology and seasonal cycle in the tropics poses special challenges for coupled ocean-atmosphere general circulation models (GCMs): The large diabatic component and the important role played by the hydrological cycle imply the need for proper treatment of subgrid-scale physical processes in the GCM. The strong interactions between the atmosphere and the ocean also impose stringent tests on the model components.

In this article we report on studies we have performed to assess the impact of physical parameterizations on the performance of the UCLA coupled GCM (CGCM). The model consists of the UCLA GCM for the global atmosphere (AGCM) and the GFDL ocean GCM for the tropical Pacific Ocean (OGCM). Detailed descriptions of the configurations and parameterizations in both model components can be found in Ma et al. (1994).

2. Sensitivity to Longwave Radiation Parameterizations

An earlier version of the UCLA CGCM which uses the Katayama (1972) scheme (the K scheme) for longwave radiative transfer in the AGCM develops a catastrophic climate drift almost from the beginning of the coupled simulation. Unrealistic distributions of

[1]Corresponding author address: Chung-Chun Ma, Department of Atmospheric Sciences, University of California, 405 Hilgard Avenue, Los Angeles, CA 90024.

sea surface temperature (SST) are produced in the tropical Pacific. Using the scheme by Harshvardhan et al. (1987, the H scheme), which is used in the current version of the UCLA AGCM, a very realistic simulation of the coupled system is obtained.

To study the effect of differences in the two longwave radiation schemes, we compared the surface fluxes produced by the uncoupled AGCM simulations with identical SST distributions. Surprisingly, the longwave radiation scheme that produces colder SSTs in the coupled simulation (the H scheme) produces stronger longwave radiation from the atmosphere into the ocean. Detailed analyses showed that the reason for this apparent contradiction has to be sought in processes other than radiative transfer. The colder SSTs obtained with the H scheme are associated with stronger evaporative cooling of the ocean surface and stronger surface windstress in the tropics, both of which are associated with stronger convective activity. The strengthening of convective activity with the H scheme is due to the stronger upper-level radiative cooling produced by the H scheme compared to the K scheme, which results in a less stable atmosphere. Further details can be found in Ma et al. (1994).

3. Impact of Stratus in the Southeastern Pacific on the CGCM Performance

Figure 1 shows the difference between the annual mean SST of an eight-year climatology of the coupled GCM simulation and observational estimates. In addition to the systematic cold bias throughout most of the model domain, there are two regions with conspicuous warm biases off the coasts of Southern California and Peru. These regions are well known for their high incidence of stratus clouds. It is natural, therefore, to ask whether these biases are related to the underestimation of stratus clouds by the AGCM. It is also tempting to conjecture that this bias could contribute to the excessively warm SSTs south of the equator in the eastern Pacific.

To study the effect of the stratus clouds on the coupled system, we performed a sen-

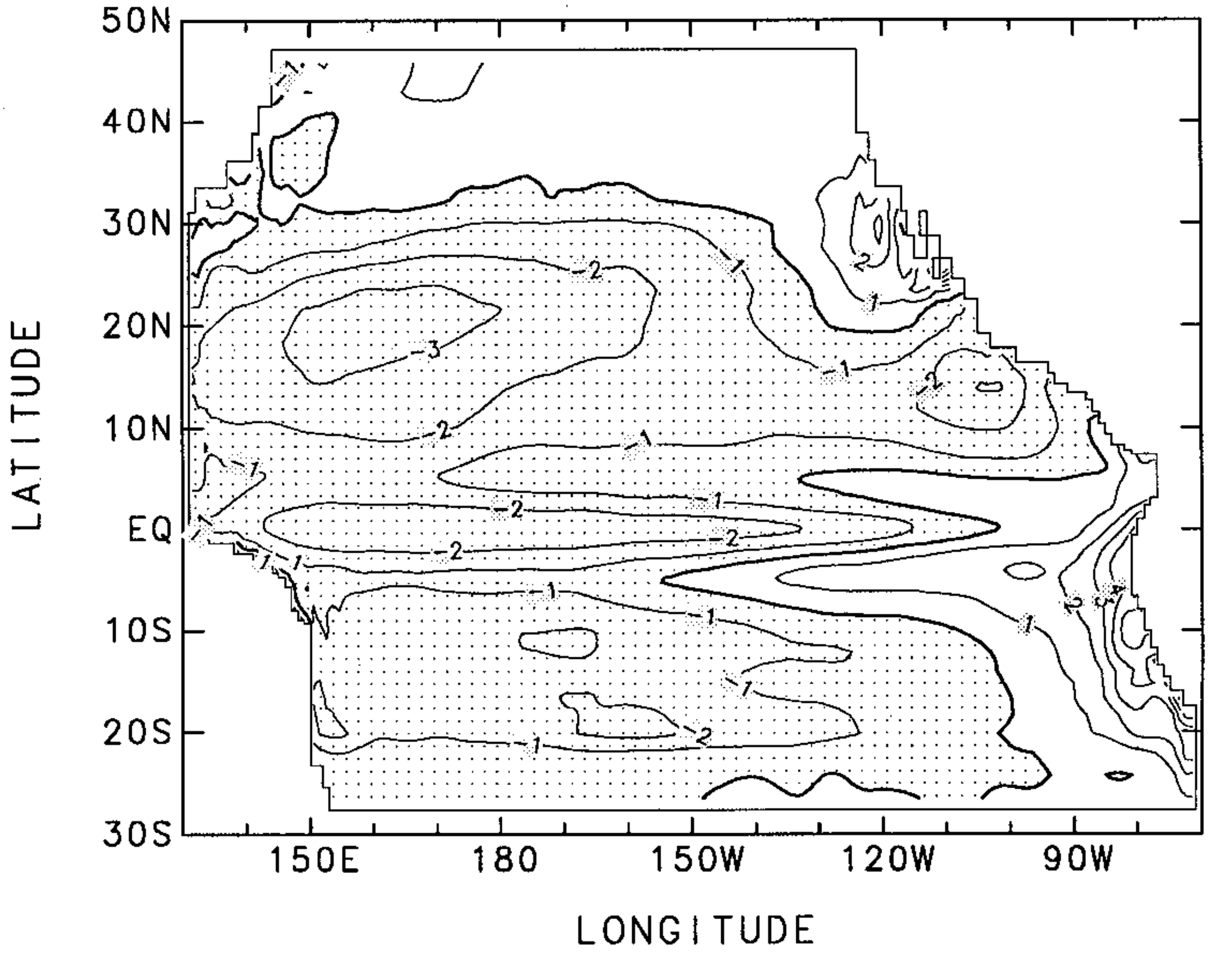

FIG. 1. Errors in annual mean SST of an eight-year climatology of coupled GCM simulation. Contour interval is 1 K.

sitivity experiment in which we prescribed the amount of stratus over the ocean between 10°S and 30°S latitude, and east of 90°W up to the coast of South America. In the region specified, the stratus amount produced by the AGCM's parameterization is ignored in the radiation calculations; instead it is assumed that at all times there is stratus present, with a thickness of 30 mb or the thickness of the planetary boundary layer (PBL), if the PBL is thinner than 30 mb. It is obvious that this prescription is far from realistic. Our purpose here is to study the relative contributions from the stratus, not to try to obtain realistic simulations by prescribing the stratus.

The July-mean SSTs from the control experiment and the experiment with stratus prescribed after one year of coupled simulations are compared in Fig. 2. There are strikingly large differences. First, in the region where the stratus is prescribed, the SST can decrease up to 5 K locally. Furthermore, the cooling is not confined to the region where stratus clouds are artificially altered; there is significant cooling throughout the entire equatorial belt between 8°S and 8°N. The SST east of 120°W south of the equator shows an overall decrease. Nevertheless, there is a tongue of warm SSTs around 5°S sandwiched between the equatorial cold tongue and a wedge of cold SSTs extending westward along 12°S from the coast of South America.

The decrease in SST in the region where stratus clouds are prescribed is expected as a result of reduced solar radiation reaching the surface due to the larger amount of stratus clouds. The influence on the SST in the cold tongue region appears to be mainly achieved by the advective process in the initial stage. The current flowing northward along the coast of Peru (the model counterpart of the Peru Current) advects the anomalously cold water northward to the equatorial region. The cooling subsequently extends westward through the advection by the South Equatorial Current.

As the SST in the cold-tongue region decreases, the surface zonal windstress in the equatorial region increases consistently with the stronger zonal gradient of SST. The increase in the westward stress induces stronger upwelling, which further reduces SST at the

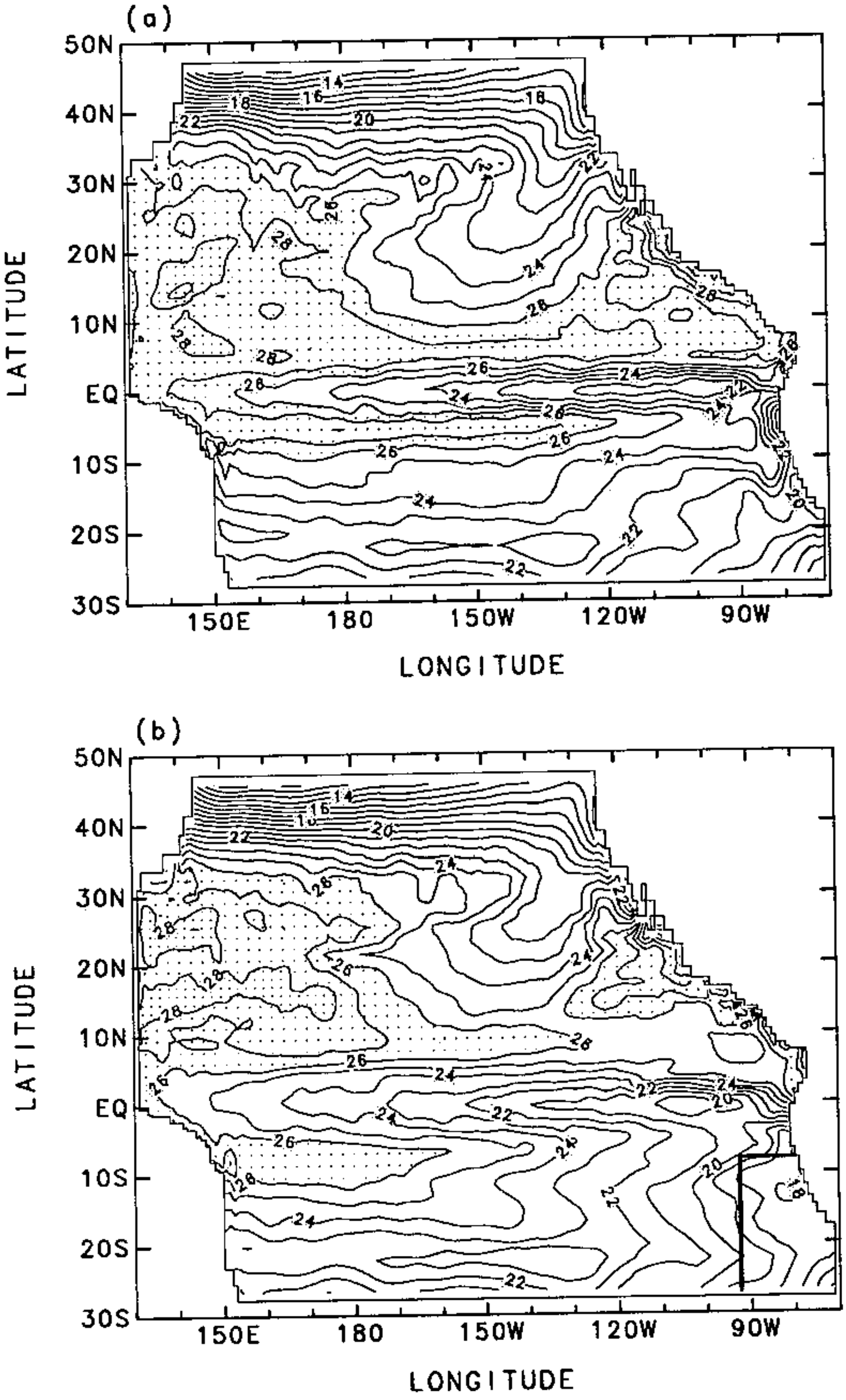

FIG. 2. Simulated July SST from (a) the control run, and (b) the run with stratus prescribed in the region enclosed by the thick lines and the coast of South America.

equator, especially in the central Pacific. The stronger zonal windstress and the stronger cold tongue (larger zonal SST gradient) are self-sustaining. As a result, the coupled system settles into a new state with high zonal stress and strong zonal SST gradient.

Admittedly, the amount of stratus in the experiment we performed is highly exaggerated. Consistently, the simulated SST in the southeastern Pacific is much too cold and the cold tongue is too strong. Nevertheless, important implications can still be inferred from the results obtained:

1) The nonlocal SST cooling by the enhanced stratus in the southeastern Pacific suggests that the advection of cold water from the coast of South America contributes partially to the low SSTs in the equatorial cold tongue. This implies that the existence of cold tongue in the Pacific and Atlantic Oceans may be closely tied to the coastal geometry and the current systems.

2) The increase in stratus cloud amount in the southeastern Pacific can reduce SSTs by up to 5 K. This is sufficient to account for the warm bias in this region in the coupled simulations.

3) Increase in stratus and colder SSTs off the coast of Peru do not seem to change the CGCM's tendency to produce a zonally-oriented belt of warm SSTs south of the cold tongue region, a problem common to contemporary coupled GCMs (Mechoso et al. 1994). Although the SST in this region is reduced in our sensitivity experiment, the zonal orientation of the warm SST still persists.

4. Conclusions

In summary, the studies we have conducted indicate the strong interaction among radiation, convection, and large-scale dynamics of the atmosphere and the ocean in the tropical region. The understanding and proper parameterization of the radiative and moist processes are key elements for improving simulations of the tropics on seasonal and interannual time scales.

Acknowledgments. This work was supported by DOE-CHAMMP under grant DE-FG03-91ER61214. Model integrations were performed at the San Diego Supercomputer Center.

References

Harshvardhan, R. Davies, D. A. Randall, and T. G. Corsetti, 1987: A fast radiation parameterization for atmospheric circulation models. *J. Geophys. Res.,* **92,** 1009–1016.

Katayama, A., 1972: A simplified scheme for computing radiative transfer in the troposphere. *Numerical Simulation of Weather and Climate,* Tech. Rep. No. 6. Dept. of Meteor., University of California, Los Angeles, 77 pp.

Ma, C.-C., C. R. Mechoso, A. Arakawa, and J. D. Farrara, 1994: Sensitivity of a coupled ocean-atmosphere model to physical parameterizations. *J. Clim.,* in press.

Mechoso, C. R., and coauthors, 1994: The seasonal cycle over the Tropical Pacific in general circulation models. Submitted to *Mon. Wea. Rev.*.